Airborne measurements of atmospheric methane using pulsed laser transmitters

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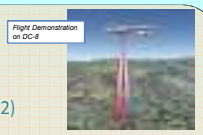
At NASA Goddard Space Flight Center, we have been developing a laser-based technology needed to remotely measure methane (CH_4) from orbit. Our lidar transmitter is based on an optical parametric process to generate near infrared laser radiation at 1651 nm, coincident with a CH_4 absorption. In an airborne flight campaign in the fall of 2015, we tested two kinds of laser transmitters --- an optical parametric amplifier (OPA) and an optical parametric oscillator (OPO). The two laser transmitters were successfully operated in the NASA's DC-8 aircraft, measuring methane from 3 to 13 km with high precision.

Background

- Methane measurements for earth science
  - Strong greenhouse gas (>x20 radiative forcing than CO2)
  - Closing the carbon budget, global coverage
  - Methane hydrate in the Arctic (where passive spectrometer won't work)
- Requirements for space instrument
  - Wavelength: ~1.65um (outside fiber amplifier band)
  - Energy: >250uJ (for 1% error, 10kHz)



Monthly Global Map of the CH_4 column-averaged volume mixing ratios from GOSAT. Note the lack of coverage at high latitudes and the tropics.

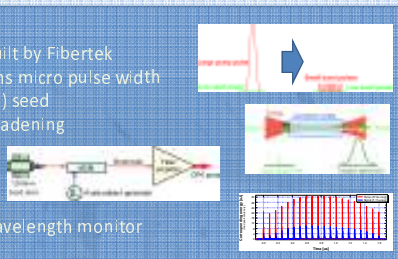
2015 CH4 airborne campaign

- Aircraft: NASA DC-8 (NA817)
  - 1 engineering & 2 science flights, total ~12 hours
  - From Armstrong Flight Research Center, CA
- Telescope: 20cm, 300urad field of view
  - Transmitter divergence: ~150urad
- Detector: DRS eAPD, 90% QE, ~10^9V/W
- Compare OPA-OPO performance

Overview

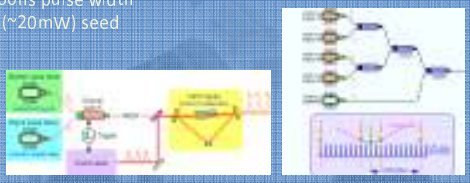
Burst-mode OPA

- Pump laser (1064nm)
  - Yb-fiber amplifier, LMA fiber, built by Fibertek
  - Burst mode, 20 micro pulses, 3ns micro pulse width
  - Works with low power (~20mW) seed
  - Minimizes output linewidth broadening
- Nonlinear crystal
  - 50mm MgO:PPLN
- Scanning seed laser
  - Beat against master laser for wavelength monitor



Seeded OPO

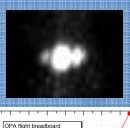
- Pump laser (1064nm)
  - Seeded, active Q-switch, Nd:YAG laser built by NASA/GSFC
  - Single pulse, ~1.5mJ, ~60ns pulse width
  - Works with low power (~20mW) seed
- Nonlinear crystal
  - 35mm MgO:PPLN
- 4 slave seed lasers
  - Optical PLL
  - Fast optical switch

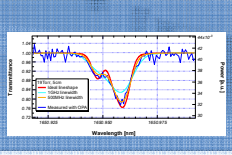


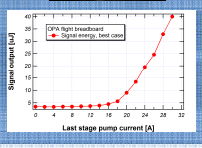
Laser source

Burst-mode OPA

- Output energy
  - Reduced to ~40uJ per burst (not enough for space)
  - Due to several simplifications for the airborne demonstration
- Linewidth: ~500MHz
- Number of wavelength: 20

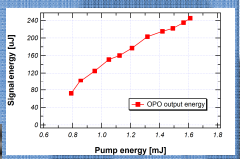


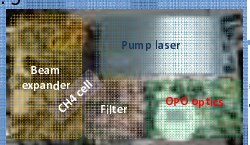


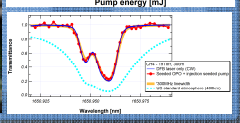


Seeded OPO

- Output energy
  - ~240uJ (satisfying requirement for space)
  - Too much energy for the airborne demonstration
- Linewidth: <~100MHz
- Number of wavelength: 5
- OPO cavity control
  - Phase modulation
  - Mirror on PZT



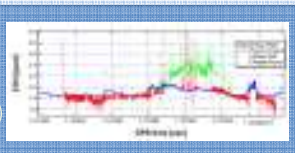




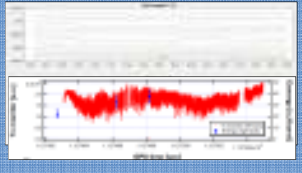
Airborne results

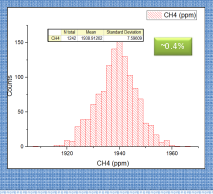
Burst-mode OPA

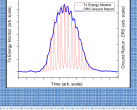
- Analysis overview
  - 1s averaging, uniform 1900ppb model
  - ~0.4% error for the best ~20min section
  - Stable signal up to the highest altitude (~13km)



- Problems identified
  - Power stability (unstable LMA fiber mode)
  - Retrieval with cloud return

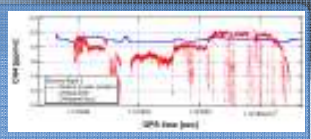


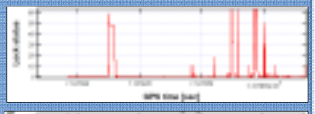


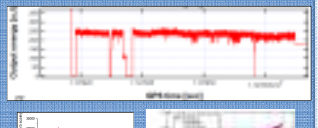


Seeded OPO

- Analysis overview
  - 1s averaging, uniform 1900ppb model
  - No DRS non-linearity correction yet
  - ~0.5% error for the best ~9 min section
  - Stable output energy
  - Detector gain minimized at low altitude







- Problems identified
  - Detector saturation (too high energy)
  - Cavity unlock (reason unknown)